

## Physics

**Bernard Gerstman**, *Professor and Chairperson*  
**Werner Boeglin**, *Professor*  
**Richard A. Bone**, *Professor*  
**David Brookes**, *Assistant Professor*  
**Prem Chapagain**, *Assistant Professor*  
**Yesim Darici**, *Associate Professor*  
**Rudolf Fiebig**, *Professor*  
**Lei Guo**, *Assistant Professor*  
**Kenneth Hardy**, *Professor Emeritus*  
**Jin He**, *Assistant Professor*  
**Laird H. Kramer**, *Associate Professor*  
**Wenzhi Li**, *Associate Professor*  
**Pete C. Markowitz**, *Professor*  
**Oren Maxwell**, *Professor*  
**Stephan L. Mintz**, *Professor Emeritus*  
**Rajamani Narayanan**, *Associate Professor*  
**Brian A. Raue**, *Professor*  
**Jorge Reinhold**, *Associate Professor*  
**Jorge L. Rodriguez**, *Assistant Professor*  
**Misak Sargsian**, *Associate Professor*  
**John W. Sheldon**, *Professor Emeritus*  
**Caroline E. Simpson**, *Associate Professor*  
**Walter Van Hamme**, *Professor*  
**Xuewen Wang**, *Associate Professor*  
**James R. Webb**, *Professor*  
**Yifu Zhu**, *Professor*

### Master of Science in Physics

The Master of Science in Physics is a 45 semester hour program consisting of course work at the 5000 and 6000 level and research with one of the departmental research groups culminating in a master's thesis. Students entering the program must have a bachelor's degree or equivalent course work in Physics.

#### Graduate Admission Requirements

For admission to the graduate programs, a Bachelor's degree in physics is required with a minimum undergraduate GPA of 3.0. The GRE is required. International graduate student applicants whose native language is not English are required to submit a score for the Test of English as a Foreign Language (TOEFL) or for the International English Language Testing System (IELTS). A total score of 80 on the iBT TOEFL or 6.5 overall on the IELTS is required.

#### Required Courses

|          |                                    |     |
|----------|------------------------------------|-----|
| PHY 5115 | Mathematical Physics I             | 3   |
| PHZ 5156 | Computational Physics I            | 3   |
| PHY 5240 | Advanced Classical Mechanics       | 3   |
| PHY 5346 | Advanced Electromagnetic Theory I  | 3   |
| PHY 5347 | Advanced Electromagnetic Theory II | 3   |
| PHY 6645 | Advanced Quantum Mechanics I       | 3   |
| PHY 6646 | Advanced Quantum Mechanics II      | 3   |
| PHY 6936 | Advanced Topics                    | 3   |
| PHY 6524 | Statistical Physics                | 3   |
| PHY 6935 | Graduate Research Seminar          | 3-6 |

In addition, three semester hours of specialized course work are required in the student's area of specialization and 12-15 hours of thesis work for a total of 45 hours.

## Doctor of Philosophy in Physics

The Doctor of Philosophy in Physics program requires 90 credit hours at the graduate level, including a minimum of 24 credit hours of dissertation research. A maximum of 36 credits may be transferred from a completed graduate program with the approval of the Graduate Committee.

#### Graduate Admission Requirements

For admission to the graduate programs, a Bachelor's degree in Physics is required with a minimum undergraduate GPA of 3.0. The GRE is required. The GRE advanced is recommended. International graduate student applicants whose native language is not English are required to submit a score for the Test of English as a Foreign Language (TOEFL) or for the International English Language Testing System (IELTS). A total score of 80 on the iBT TOEFL or 6.5 overall on the IELTS is required.

#### Required Courses

1. All Required Courses for the Master of Science in Physics program listed above.
2. Four additional graduate level (5000 or higher) courses.

All doctoral candidates must take a Ph.D. comprehensive exam. This exam is designed to test general knowledge of physics at the advanced undergraduate and first-year graduate level and must be passed not later than the beginning of the third year enrolled in the program. Within two years of entering the program, students must submit to the Graduate Committee their choices of research and advisor. Course work and research programs shall be planned with the advice and approval of the advisor. After passing the comprehensive exam and prior to or during the first semester of the fourth year enrolled in the program, a student must also take a candidacy exam which tests the ability to conduct research in a particular field, as well as the ability to present the results of that research in an organized and coherent manner.

## Course Descriptions

### Definition of Prefixes

AST-Astronomy; PHY-Physics; PHZ-Physics  
 F-Fall semester offering; S-Spring semester offering; SS-Summer semester offering.

**AST 5215 Stellar Astrophysics (3).** Topics in Stellar Astrophysics, in greater detail and depth than similar topics in AST 3213. Emphasis on current stellar structure, evolution models and the underlying observational data. Prerequisites: PHY 3107, PHY 3503, PHY 4324, PHY 4222 or equivalent. (F or S)

**AST 5405 Extragalactic Astrophysics (3).** Topics in extragalactic astrophysics, in greater detail and depth than similar topics in AST 3213. Emphasis on galactic structure and evolution, quasars and cosmology. Prerequisites: PHY 3107, PHY 3503, PHY 4324, PHY 4222 or equivalent. (For S)

**AST 5507 Celestial Mechanics (3).** Principles of classical Newtonian mechanics applied to the motions of planets, satellites, and interplanetary space probes. Prerequisites: PHY 4222 or equivalent. (F or S)

**PHY 5115 Mathematical Physics I (3).** Methods of solution for problems in mathematical physics: Variational principles, complex variables, partial differential equations, integral equations, and transforms. Prerequisites: MAC 3313, MAP 3302. (F)

**PHY 5116 Mathematical Physics II (3).** Additional solution methods in mathematical physics: Perturbation methods, Laplace's and Poisson's Equations, waves, special functions, vector fields, vector waves. Prerequisite: PHY 5115. (S)

**PHY 5141 Intermediate Modern Physics I (3).** Prepares advanced undergraduate and beginning graduate student research preparation in atomic, molecular, or optical physics. Topics may be adapted to students' research interests. Prerequisite: Permission of Instructor.

**PHY 5142 Intermediate Modern Physics II (3).** Continuation of advanced undergraduate and beginning graduate student research preparation in atomic, molecular, optical or nuclear physics. Topics may be adapted to students' research interests. Prerequisite: Intermediate Modern Physics I.

**PHY 5156C Physics Modeling II (4).** Expanding the modeling guided-inquiry approach in Physics Modeling I to topics beyond mechanics such as electricity, magnetism, light, or modern physics. May be repeated for credit. Prerequisites: PHZ 5155C and permission of the instructor.

**PHY 5235 Nonlinear Dynamics and Chaos (3).** Introduction to the universal behavior of classical systems described by nonlinear equations. Prerequisites: PHY 4222, MAA 4211. (F or S)

**PHY 5240 Advanced Classical Mechanics (3).** Advanced formulations of the equations of motion and their applications: the central field problem, rigid body dynamics, oscillations and continuous systems. Prerequisite: PHY 4222. (F)

**PHY 5346 Advanced Electromagnetic Theory I (3).** Advanced treatment of classical electromagnetism: Electrostatics, Green's function, Laplace's equation, multipole expansion, magnetostatics, Maxwell's equations, waves. Prerequisite: PHY 4324. (F)

**PHY 5347 Advanced Electromagnetic Theory II (3).** Additional topics in classical electromagnetism: Wave guides, radiating and diffracting systems, Kirchoff's integral for diffraction, covariant formulation of field equations. Prerequisite: PHY 5346. (S)

**PHY 5446 Laser Physics (3).** Principles of lasers and laser applications, including atom-field interactions, stimulated emission and dipole oscillators, optical resonators and electromagnetic modes, semi-classical laser theory, and specific laser systems. Prerequisite: PHY 4605. (F or S)

**PHY 5466 The Physics of Music (3).** Provides music technology majors a physical understanding of sound, sound generation and reproduction. Concentrates mainly on physical principles and less on calculation. Prerequisite: Permission of Instructor.

**PHY 5667 Nonperturbative Quantum Field Theory (3).** Euclidean QFT, renormalization group, local gauge symmetry, lattice regularization, Wilson action, fermion

fields, expansion schemes, numerical algorithms, hadron properties, recent developments. Prerequisite: PHY 4605.

**PHY 5930 Seminar in Physics (1-3).** A series of specialized lectures/seminars on selected topics in Physics/Astro-Physics. Prerequisite: Permission of the department.

**PHY 5936 Special Topics Research (1-10).** Participation in an original investigation in theoretical or experimental physics/astro-physics under direct faculty supervision. Prerequisite: Permission of the instructor.

**PHY 5937, PHY 5938 Seminar in Special Topics (3).** Seminar work under the supervision of a faculty member on subject material of mutual interest.

**PHY 5940 Physics Graduate Teaching Workshop (1).** The teaching of physics laboratories. Includes practice of lab experiments, use and adjustment of lab equipment and explanation of departmental grading policy. Supplemented by outside lectures on university policies. (F)

**PHY 6524 Statistical Physics (3).** Fundamental principles of statistical mechanics; fluctuations, noise and irreversible thermodynamics; kinetic methods and transport theory. Prerequisites: PHY 3503 and PHY 4222. (S)

**PHY 6645 Advanced Quantum Mechanics I (3).** Advanced topics in quantum mechanics: Quantized systems, relativistic quantum mechanics, potential scattering. Prerequisite: PHY 4605. (F)

**PHY 6646 Advanced Quantum Mechanics II (3).** Additional topics in advanced quantum mechanics: Collision theory, symmetry transformations, conservation laws, group theory. Prerequisite: PHY 6645. (S)

**PHY 6651 Quantum Scattering Theory I (3).** The investigation of atomic and electronic scattering processes: Potential scattering, long range potentials, electronatom collisions. Prerequisite: PHY 6645.

**PHY 6652 Quantum Scattering Theory II (3).** The mathematical investigation of scattering processes: Auto-ionization, fast vs. slow collisions, Regge poles, S and T matrices. Prerequisite: PHY 6651.

**PHY 6668 Relativistic Quantum Field Theory I (3).** Introduction to relativistic quantum fields: General formalism, Klein-Gordon field, Dirac field, vector fields, interacting fields, CPT theorem, reduction formulae, gauge theory. Prerequisite: PHY 6646.

**PHY 6669 Relativistic Quantum Field II (3).** Additional topics in relativistic quantum fields: perturbation theory, U matrix, Wick's theorem, dispersion relations, renormalization, Ward identity, renormalization group, path integral formalism. Prerequisite: PHY 6668.

**PHY 6675 Quantum Theory of Many Particle Systems I (3).** An introduction to the physics of many particle systems: Second quantization, Fock spaces, Boson and Fermion symmetry, Gell-Mann-Low theorem, diagrammatic expansions, Goldstone theorem. Prerequisite: PHY 6646.

**PHY 6676 Quantum Theory of Many Particle Systems II (3).** Additional topics in the physics of many particle systems: Fermi gas, Bose condensation, Hartree-Fock

approximation, random phase approximation, finite temperature formalism, hadrons. Prerequisite: PHY 6675.

**PHY 6716 Advanced Biophysics (3).** Thermodynamics, statistical physics, and the non-linear dynamics of self-organization will be used to investigate the molecular origin of life and neural pattern formation leading to consciousness.

**PHY 6935 Graduate Research Seminar (1).** Seminars presented by students, faculty, and visitors on a variety of topics of current research interest. Repeatable. Required every semester. (F and S)

**PHY 6936 Advanced Topics in Physics (3).** Advanced applications in the fields of Nuclear and Particle Physics, Astrophysics, Solid State Physics, Biophysics and Atomic Physics. Includes perturbations theory, statistical methods, and simulation methods. Repeatable for credit. Prerequisite: PHY 6646.

**PHY 6939 Graduate Research (1-10).** Research at the graduate level in theoretical or experimental physics under faculty supervision, repeatable. Prerequisite: Permission from supervising faculty.

**PHY 6970 Thesis Research (1-10).** Research toward completion of Master's Thesis. Repeatable. Prerequisite: Permission of the department. (F,S)

**PHY 6971 Master's Thesis (3).** Theoretical and/or experimental research leading to thesis. Prerequisite: Permission of major professor. (F,S)

**PHY 7910 Dissertation Research (1-9).** Students conduct dissertation research at the doctoral level in theoretical or experimental physics under faculty supervision. Prerequisite: Permission of the instructor. (F, S)

**PHY 7981 Ph.D. Dissertation (1-12).** Original research work towards completion of dissertation and presentation and defense of dissertation. Prerequisite: Permission of Major Professor and Doctoral Candidacy.

**PHZ 5130 Theoretical Treatment of Experimental Data (3).** Statistical analysis of physical processes and statistical tests, with particular emphasis on instrumentation-related problems. Mathematical modeling and computer simulation. Prerequisites: Undergraduate statistics course, or equivalent, or permission of the instructor.

**PHZ 5155C Physics Modeling I (4).** An inquiry physics-teaching approach incorporating physics education research. Emphasis on basics models in mechanics, scientific discourse, and student learning assessment. May be repeated for credit. Prerequisite: Permission of the instructor.

**PHZ 5156 Computational Physics I (3).** Physical systems by means of computer simulation. Monte Carlo, molecular dynamics, percolation, random systems, chaos, criticality, gauge fields. Prerequisites: PHY 5115 and PHY 5116.

**PHZ 5157C Computational Physics II (3).** Advanced computer simulation methods of physical systems. Application in chaos, nonlinear and random systems, criticality, field theory and practices. Prerequisite: PHZ 5156. Corequisites: PHY 5115 and PHY 5116.

**PHZ 5234 Atomic and Molecular Collision Phenomena (3).** Investigation of atomic and molecular collision phenomena: Kinetic theory, elastic scattering, inelastic scattering, excitation and ionization, heavy particle collisions. Prerequisites: PHY 4605 and PHY 4222. (F or S)

**PHZ 5304 Advanced Nuclear Physics (3).** The fundamental properties of nuclei, nuclear forces, nuclear models, radioactivity, weak processes, and nuclear reactions. Prerequisite: PHY 4604. Corequisite: PHY 4605. (F or S)

**PHZ 5340 Particle Interactions and Detection (3).** Subatomic particle detectors and the utilization of physics in practical instrumentation applications in medical physics. The course will include laboratory exercises using various detectors. Prerequisites: PHY 3107 or permission of Instructor.

**PHZ 5370 Nanoscience (3).** Overview of the nanoscience with emphasis on physical properties, such as electrical, magnetic and optical properties, of nanomaterials. Prerequisites: PHY 3106, PHY 3107.

**PHZ 5405 Solid State Physics (3).** Crystalline form of solids, lattice dynamics, metals, insulators, semiconductors, crystalline surfaces, and amorphous materials. Prerequisites: PHY 3107 or CHM 3411.

**PHZ 5505 Low Energy Plasma Physics (3).** The investigation of the kinetics of rarefied gases and thermal plasmas: Phase space, random currents, orbit theory, plasma sheaths, radiation, the pinch effect. Prerequisites: PHY 3503, PHY 4324, and PHY 4222.

**PHZ 5506 Plasma Physics (3).** An introduction to plasma fundamentals, the Boltzmann equation, the hydrodynamic equations, orbit theory, the interaction of electromagnetic waves with plasmas, the pinch effect and instabilities. Prerequisite: PHY 3049. (F or S)

**PHZ 5606 Special Relativity (3).** A detailed study of special relativity: Lorentz transformations, relativistic electrodynamics. Prerequisite: PHY 3107.

**PHZ 5607 General Relativity (3).** General relativity using differential geometry and tensor analysis. Topics include Einstein's field equations and their solutions, applications and observational tests. Black Holes and cosmology are also discussed. Prerequisites: PHY 4222 and PHY 4605.

**PHZ 5705 Biomedical Physics (3).** Physics principles applied to biology and medicine; transport through cell membranes, biochemical signaling, thermodynamics, neurons, biomechanics, biofluid flow, bioelectrical signals. Prerequisite: PHY 3107.

**PHZ 5730 Biophysical Effects of Radiation (3).** Biological effects resulting from interactions of radiation and matter for scientifically, technically, and medically oriented students. Prerequisite: PHY 3107.

**PHZ 5732 Clinical and Medical Dosimetry (3).** Practical patient dosimetry problems in radiation oncology. Irregular field calculations, two-and three-dimensional treatment planning, isodose distribution, dose rate brachytherapy planning. Prerequisite: PHY 3107.

**PHZ 5734 Nuclear Medicine Physics (3).** The nuclear physics principles of diagnostic and therapeutic applications of radionuclides, radiation beams, with lab activities in facility design, instrumentation essentials, quality assurance. Prerequisite: PHY 3107.

**PHZ 5736 Therapeutic Radiological Physics (3).** Production, application, and measurement of electromagnetic radiation and particle beams in therapeutic practice. Conceptual, instrumental, and methodological aspects of therapeutic radiology. Prerequisite: PHY 3107.

**PHZ 5945 Clinical Experience in Medical Physics (3).** Arranged through the Physics Department at local institutions e.g. hospitals, treatment centers, etc., this course places students in clinical medical physics facilities. Prerequisite: PHY 3107.

**PHZ 6255 Molecular Biophysics (3).** The use of theoretical physics techniques to investigate biological systems: Protein structure and dynamics, electron tunneling, nuclear tunneling, hemoglobin, photosynthesis, vision. Prerequisite: PHY 4605. (F or S)

**PHZ 6326 Low Energy Nuclear Physics I (3).** Introduction to the physics of nuclei and nuclear processes: Nuclear forces, scattering processes and nuclear models. Prerequisite: PHY 4605.

**PHZ 6327 Low Energy Nuclear Physics II (3).** Additional topics in nuclear physics: The shell and collective models, nuclear reactions and applications, scattering theory, entrance channel phenomena, rearrangement collision and breakup reactions. Prerequisite: PHZ 6326.

**PHZ 6354 Introduction to Particle Physics (3).** An introduction to modern particle theory: Elementary field theory, symmetries, quantum electrodynamics, quark-parton model, quantum chromodynamics, Weinberg-Salam model. Prerequisite: PHY 6646.

**PHZ 6355 High Energy Hadronic Physics (3).** Physics of quark-gluon structure of strongly interacting matter. Introduces the basic methods of high energy hadronic and nuclear physics, the quark model of hadrons, and the partonic model of deep-inelastic scattering. Prerequisite: Graduate standing.

**PHZ 6359 Quantum Gauge Field Theories (3).** Basics in field quantization, nonabelian symmetries, the standard  $SU(3) \times SU(2) \times U(1)$  model, non-perturbative features, lattice regularization and numerical simulation. Prerequisites: PHY 4605, PHY 5346. (F or S)

**PHZ 6396 Advanced Nuclear and Particle Physics (3).** Nuclear and particle physics, nuclear forces, reactions and kinematics, deep inelastic scattering, partons QCD, nuclear and particle astrophysics, quark gluon plasma. Prerequisite: PHY 4604.

**PHZ 6426 Advanced Solid State Physics (3).** Electronic structures of solids and surfaces, electron-electron interaction, superconductivity, magnetism in solids, amorphous systems, glasses, polymers, percolation, localization, phase transition, fractals. Prerequisites: PHY 4324 and PHY 4605. (F or S)

**PHZ 6437C Surface Physics (3).** An introduction to theoretical and experimental techniques AES (Auger Electron Spectroscopy), LEED (Low Energy Electron

Diffraction), XPS (X-ray Photoelectron Spectroscopy), AFM (Atomic Force Microscopy) and STM (Scanning Tunneling Microscopy). Prerequisites: PHZ 5405 or permission of the instructor.